NAVAL FACILITIES ENGINEERING SERVICE CENTER
Port Hueneme, California 93043-4370

Site Specific Report

SSR-6183-OCN

CONCEPT STUDY - *MOORING SERVICE TYPE III* FOR A CVN-68 AT NAVSTA MAYPORT, FL

by

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Report Prepared for:

Commander-In-Chief, U.S. Atlantic Fleet

EXECUTIVE SUMMARY

A NIMITZ Class (CVN-68) aircraft carrier may be berthed at Naval Station, Mayport, FL. The ship may be under repair for extended time which calls for *Mooring Service Type III*. Therefore, Southern Division, Naval Facilities Engineering Command (SOUTHNAVFACENGCOM) tasked the Naval Facilities Engineering Service Center (NFESC) to perform a concept study and to estimate costs for mooring at Wharf FOXTROT.

Evaluation of the present situation shows that neither the ship's mooring fittings nor the existing wharf mooring fittings have adequate strength for the design winds of 110 mph and design current speed of 3.1 knots at the site. Therefore, it is recommended that chain and driven plate anchors be used to resist breasting forces. Existing ship's fittings may be adequate on the bow, however, a padeye system is required on the ship's stern to safely moor the ship in design environmental conditions. Ship's lines, together with extra bollards on the wharf, are used as spring lines and as auxiliary breasting lines in this concept, Figure 1.

Estimated costs for providing CVN-68 *Mooring Service Type III* at NAVSTA Mayport, FL are summarized in Table 1.

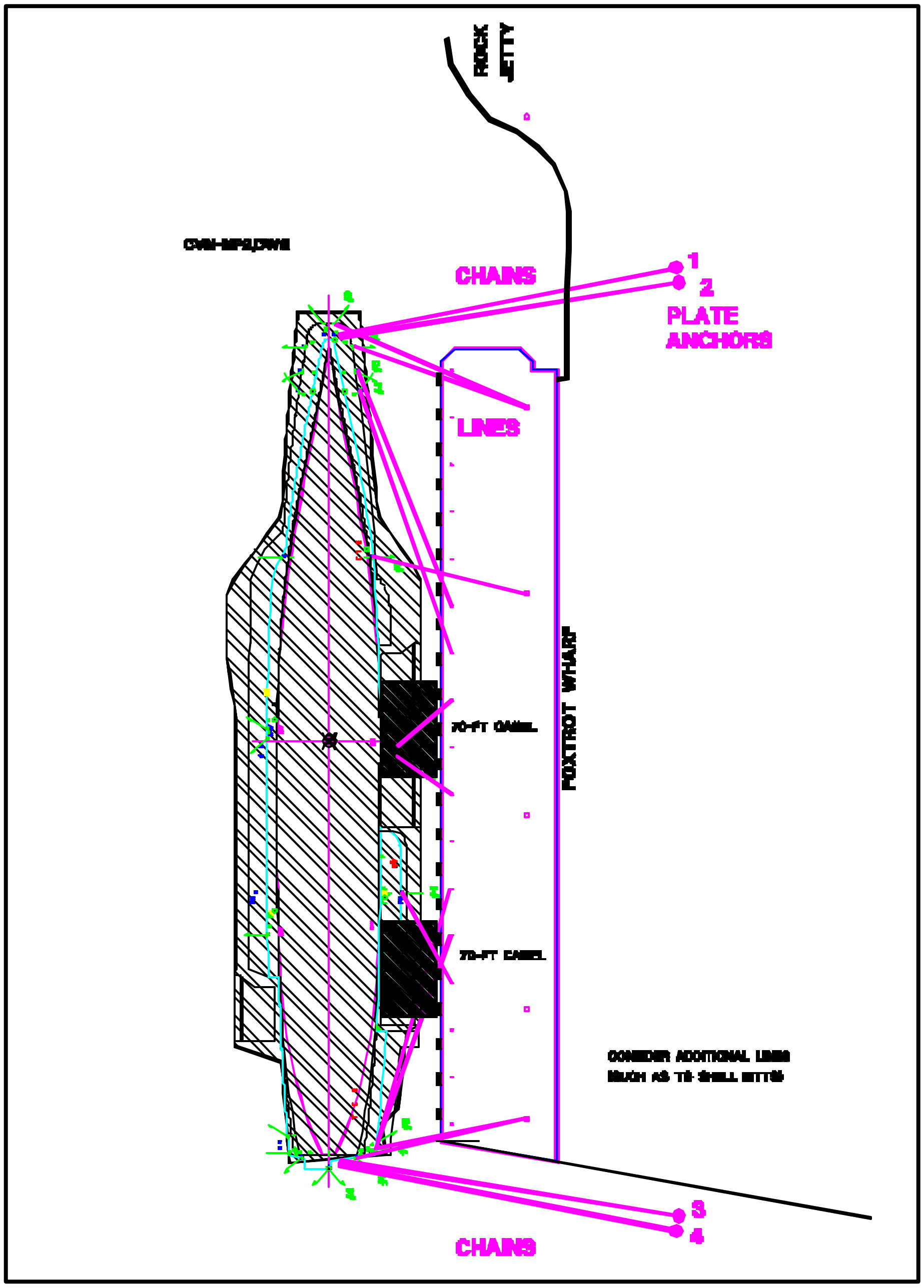

Figure 1. ***MOORING SERVICE TYPE III*** **CONCEPT FOR A CVN-68**

Table 1. PRELIMINARY FACILITIES COST ESTIMATE

***MOORING SERVICE TYPE III* CONCEPT FOR**
A CVN-68 AT WHARF FOXTROT (NAVSTA MAYPORT)*

ITEM	*ESTIMATED COST*
DESIGN	$120,000
MATERIALS	$1,422,000
INSTALLATION	$1,325,000
Sub-Total=	$2,867,000
Contingency (15%)	$430,000
Total (rounded) =	$3,300,000

* does not include utilities, dredging, etc.

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1.0 INTRODUCTION/PURPOSE

A NIMITZ Class (CVN-68) aircraft carrier may be berthed at Naval Station, Mayport, FL. While at Mayport, the ship may be under repair for an extended amount of time, including during the hurricane season, so *Mooring Service Type III* would be required at Wharf FOXTROT. Therefore, Southern Division, Naval Facilities Engineering Command (SOUTHNAVFACENGCOM) tasked the Naval Facilities Engineering Service Center (NFESC) to perform a concept study and to estimate facility upgrade costs.

2.0 DESIGN CRITERIA

2.1 SHIP

USS NIMITZ (CVN-68) class ships are used in this study. Figure 2.1 shows the ship in perspective view and Figure 2.2 illustrates the overall shape of the hull. Table 2.1 gives some ship parameters. Additional ship information and predicted forces and moments (NAVFAC Ships Database, 1998) are provided in Appendix A. In this study the ship is assumed to be in the 'light' condition with a draft of 31.2 feet. Wind forces will be on the order of 10% less for a ship in the loaded condition.

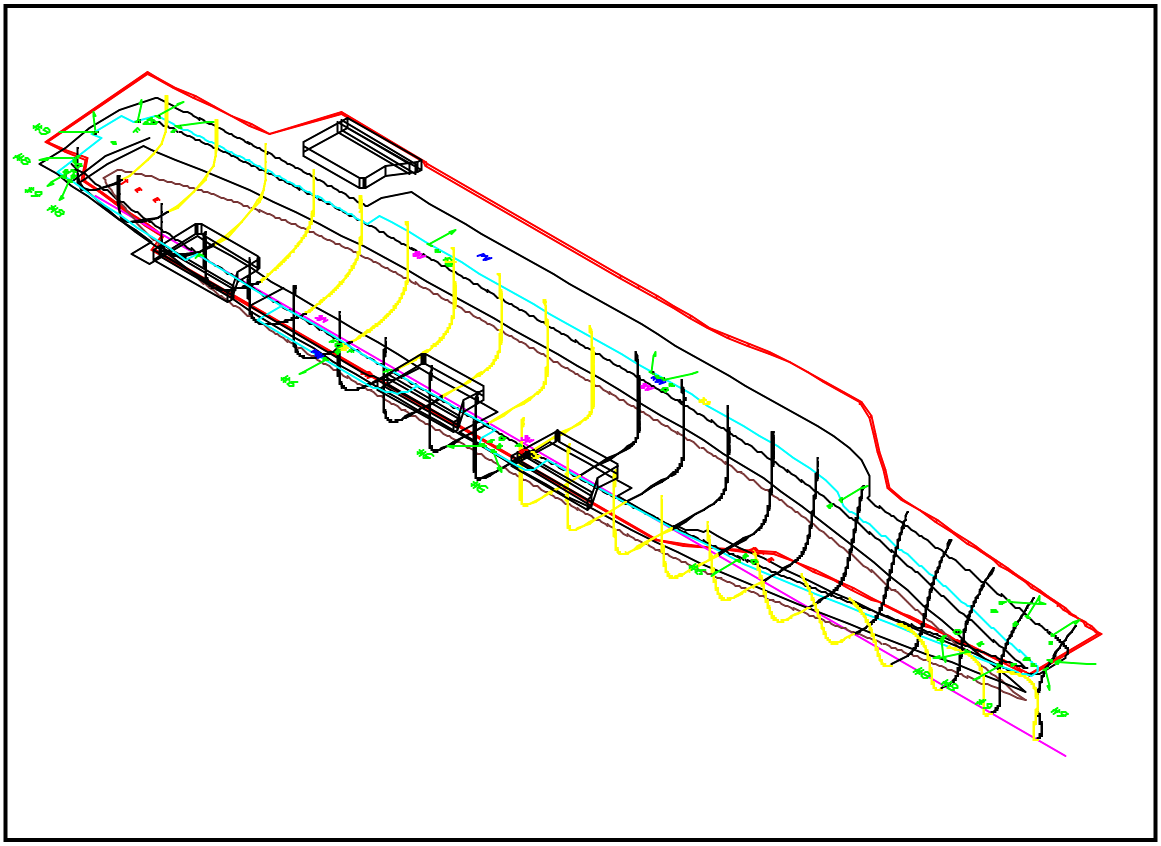


Figure 2.1 PERSPECTIVE VIEW OF USS NIMITZ (CVN-68)

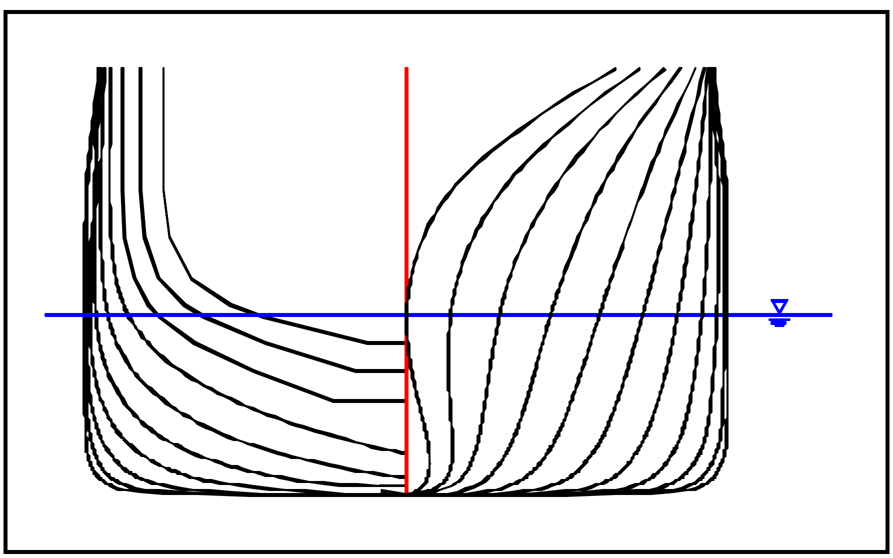


Figure 2.2 LINES PLAN FOR CVN-68 HULL

Methods in DoD Mooring Manual (in prep. 1998) are used to determine wind and current forces and moments on a CVN-68 (see Appendix A). Figure 2.3 and Table 2.2 show predicted broadside forces for winds and currents. Note that a “kip” is 1 000 pounds of force (a “kip” is 4.45K N, where N=newton).

It is recommended that *Mooring Service Type III* be provided at Wharf FOXTROT, because the ship may not be able to put to sea for extended periods of time (NAVSEASYSCOM ltr Ser 04XI/174 of 21 Aug 98).

Table 2.1 CVN-68 CRITERIA (Light)

PARAMETER	DESIGN BASIS (SI units)	DESIGN BASIS (English units)
Length Overall At Waterline Between Perpendiculars	 249.9 m 233.2 m 237.1 m	 115 ft 1 056 ft 1 040 ft
Beam @ Waterline	32.3	134 ft
Draft	9.51 m	31.2 ft
Displacement	7.50E7 kg	73 831 long tons
Bitt Size	-	12 inches
Nylon 3-Strand 9-in Lines (4@600ft)	Fb=8E5 N	Fb=180 kips
Nylon 3-Strand 8-in Lines (4@600ft)	Fb=6.5E5 N	Fb=146 kips
Nylon 3-Strand 6-in Lines (4@600ft)	Fb=3.7E5 N	Fb=82.8 kips
Wire Rope 2-in dia (4@ 600 ft)	Fb=12.8E5 N	Fb=288 kips
Anchor Chain 4.75-in Di-Lok (12 shots each side)	Fb=1.13E7 N	Fb=2 550 kips

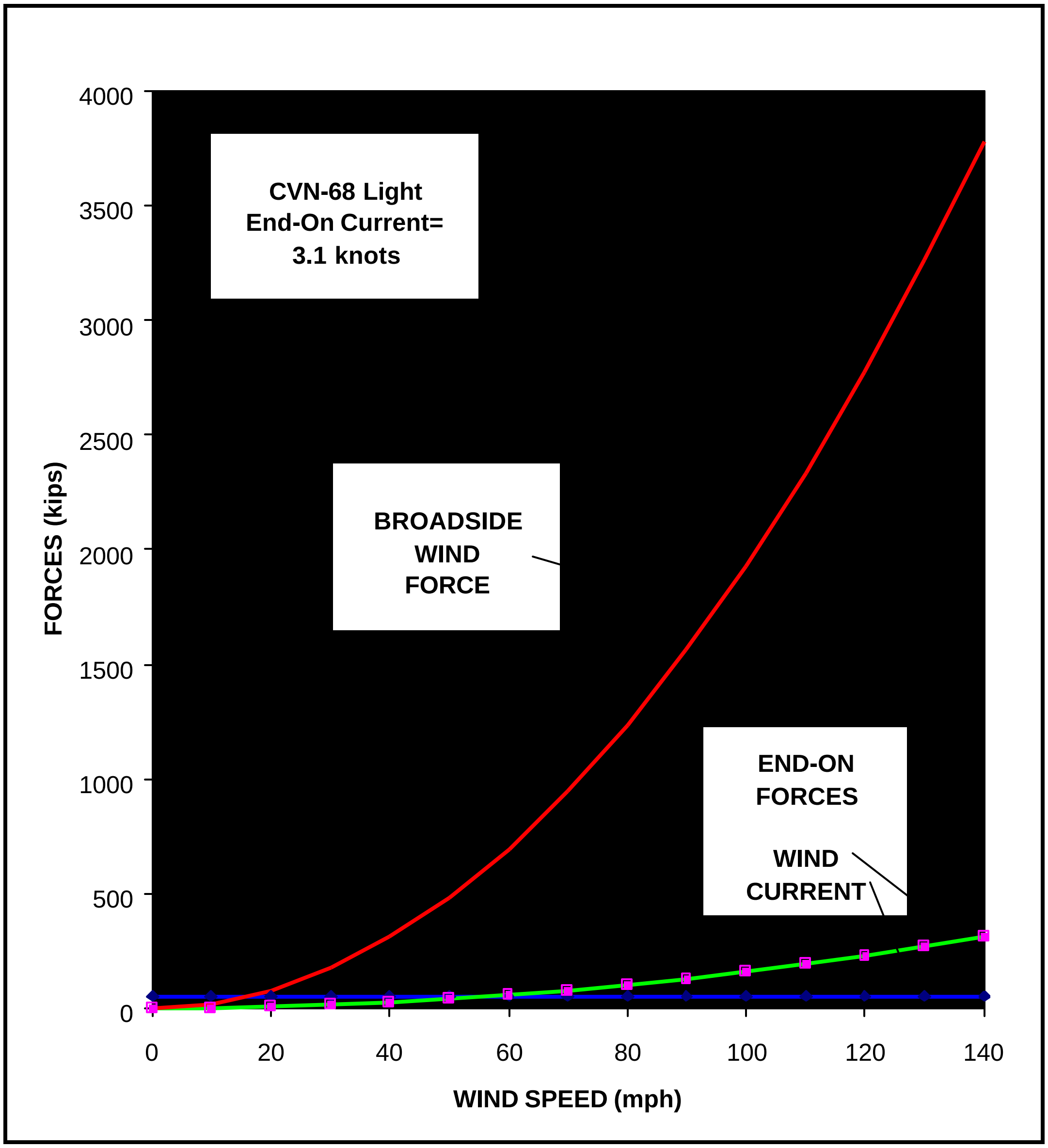


Figure 2.3 FORCES ON A CVN-68 IN THE LIGHT CONDITION

Table 2.2 ENVIRONMENTAL FORCES ON CVN-68 IN THE LIGHT CONDITION*

Wind Speed (mph)	*Fxc (kips)*	*Fxw(kips)*	*Fyw(kips)*
0	55	0	0
10	55	2	19
20	55	6	77
30	55	14	174
40	55	26	309
50	55	40	482
60	55	57	694
70	55	78	945
80	55	102	1 235
90	55	129	1 562
100	55	160	1 929
110	55	193	2 334
120	55	230	2 778
130	55	270	3 260
140	55	313	3 781

*end-on current speed = 3.1 knots

2.2 ENVIRONMENTAL CRITERIA

Mooring Service Type III environmental criteria for NAVSTA Mayport, FL are given in Table 2.3.

Table 2.3 NAVSTA MAYPORT, FL *MOORING SERVICE TYPE III* ENVIRONMENTAL DESIGN CRITERIA*

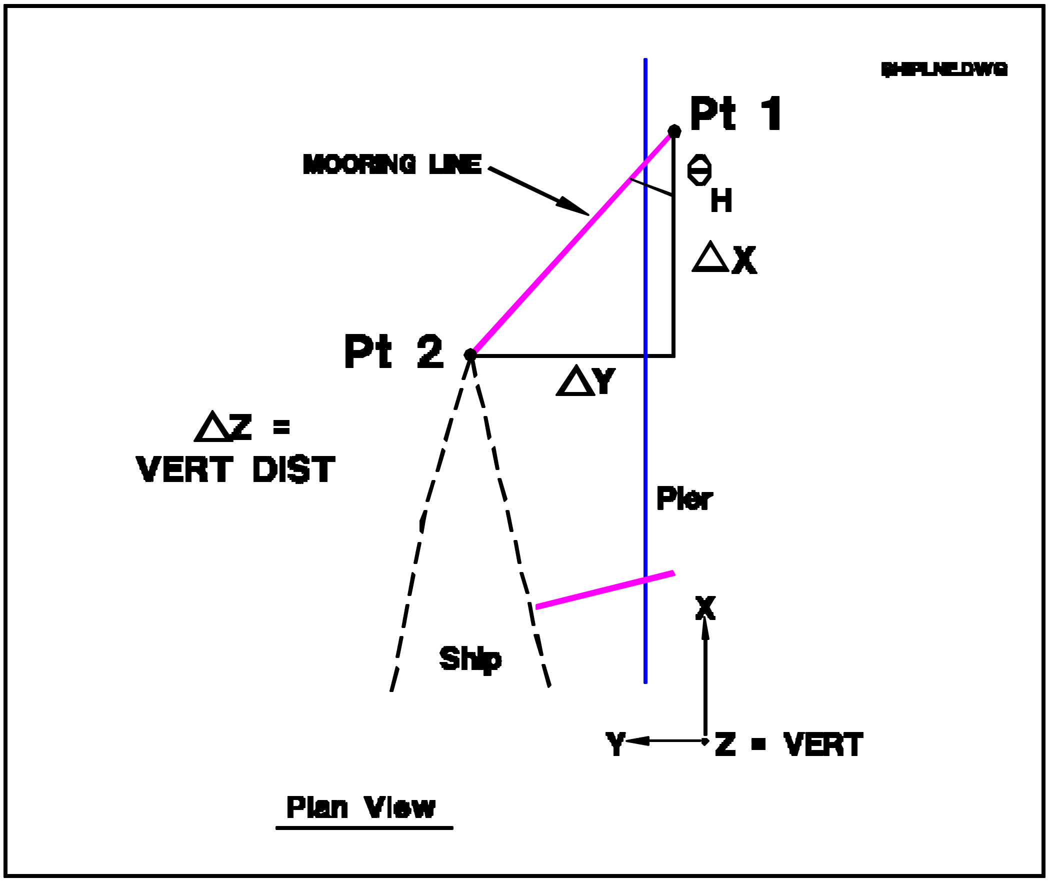
PARAMETER	*VALUE*
30-Sec Wind Speed with a Return Interval of R = 50 years and exposure D	110 mph
Current Speed	3.1 knots
Extreme High Water	7.5 ft
Extreme Low Water	-3.2 ft
Design Waves**	4 to 5 ft

* developed by NAVFAC Criteria Office

** waves may be very complex

2.3 DEFINITIONS

In this report we define a coordinate system with "X" parallel to the pier or wharf, as shown in Figure 2.4. Then "Y" is a distance perpendicular to the wharf in a seaward direction and "Z" is a vertical distance. Let "Pt 2" be the ship chock coordinate and "Pt 1" be the pier fitting. A spring line is defined as a line whose angle in the horizontal plane is less than 45 degrees and a breasting line whose angle in the horizontal plane is greater than or equal to 45 degrees, as shown in Figure 2.4.



DEFINITIONS:

$$\theta_H = \tan^{-1} \left| \frac{\Delta Y}{\Delta X} \right|$$

$$\theta_V = \tan^{-1} \left| \frac{\Delta Z}{\Delta Y} \right|$$

IF $|\theta_H| < 45$ deg $\longrightarrow$ SPRING LINE

IF $|\theta_H| \geq 45$ deg $\longrightarrow$ BREASTING LINE

Figure 2.4 DEFINITIONS

3.0 EXISTING WHARF FOXTROT

Wharf FOXTROT at NAVSTA Mayport, FL has a length of 1 020.63 feet and an elevation of approximately 12 feet above Mean Low Water (MLW). There are double bitts placed near the edge of the wharf with a spacing of approximately 60 feet along the wharf. These bitts have a maximum working capacity of 37 tons at a 45-degree up angle and 61 tons with horizontal loading. There are four storm bollards set back 110 feet from the face of the wharf. These high capacity storm bollards have a working capacity of 265 tons with a line up-angle of 16 degrees.

4.0 CONCEPT DEVELOPMENT

Various ideas are explored in this section to develop a mooring concept.

4.1 SHIP'S LINES

Table 4.1 lists the standard lines and wire ropes carried by CVN-68. In theory, the four wire ropes could be used as spring lines and the synthetic lines all used as breasting lines. These lines are long enough so two parts could be used at Wharf FOXTROT. In this case the sum of the break strength of all the wires and lines is 4.5 million pounds (after a 15% reduction in strength is taken for wet nylon line).

Table 4.1 CVN-68 STANDARD MOORING LINES

LINE	*SIZE (in)*	*NUM*	*Fb (kips)*	*Fb eff (kips)*	*PARTS*	*Total (kips)*
Nylon 3-Strand	9	4	180	153	2	1 224
Nylon 3-Strand	8	4	146	124.1	2	993
Nylon 3-Strand	6	8	82.8	70.38	2	1 126
Wire Rope (dia.)	2	4	288	288	1	1 152
					Total (kips)=	4 495

The concept of mooring efficiency (W. Seelig, NFESC TR-6005-OCN, 1997) is used to estimate the maximum safe wind speed for a mooring using the ship's lines and wire ropes. Figure 4.1 shows maximum safe wind speed vs. mooring efficiency. For example, with a mooring efficiency of e = 0.7 (which is relatively high), the maximum safe wind speed for mooring would be 63 mph with a factor of safety of 3 on all lines.

At NAVSTA Mayport the design wind is 110 mph. Wind forces and moments are proportional to wind speed squared, so the number of lines and wire ropes needed for *Mooring Service Type III* would be $(110 \text{ mph}/63 \text{ mph})^2 = 3$ (i.e. the number of lines needed is approximately three times as many as the ship's normal compliment with a factor of safety of 3 on all mooring lines). This is a problem, because the ship's fittings could not accommodate that many lines.

Inspection of Figure 2.3 shows that the end-on wind and current forces are relatively manageable, because the ship is streamlined in the longitudinal direction. This suggests that existing ship's lines and/or wire ropes could be used as spring lines to safely moor the ship and could supplement a breasting system.

However, it is clear that lines alone are unlikely to be able to breast the ship in 110 mph winds.

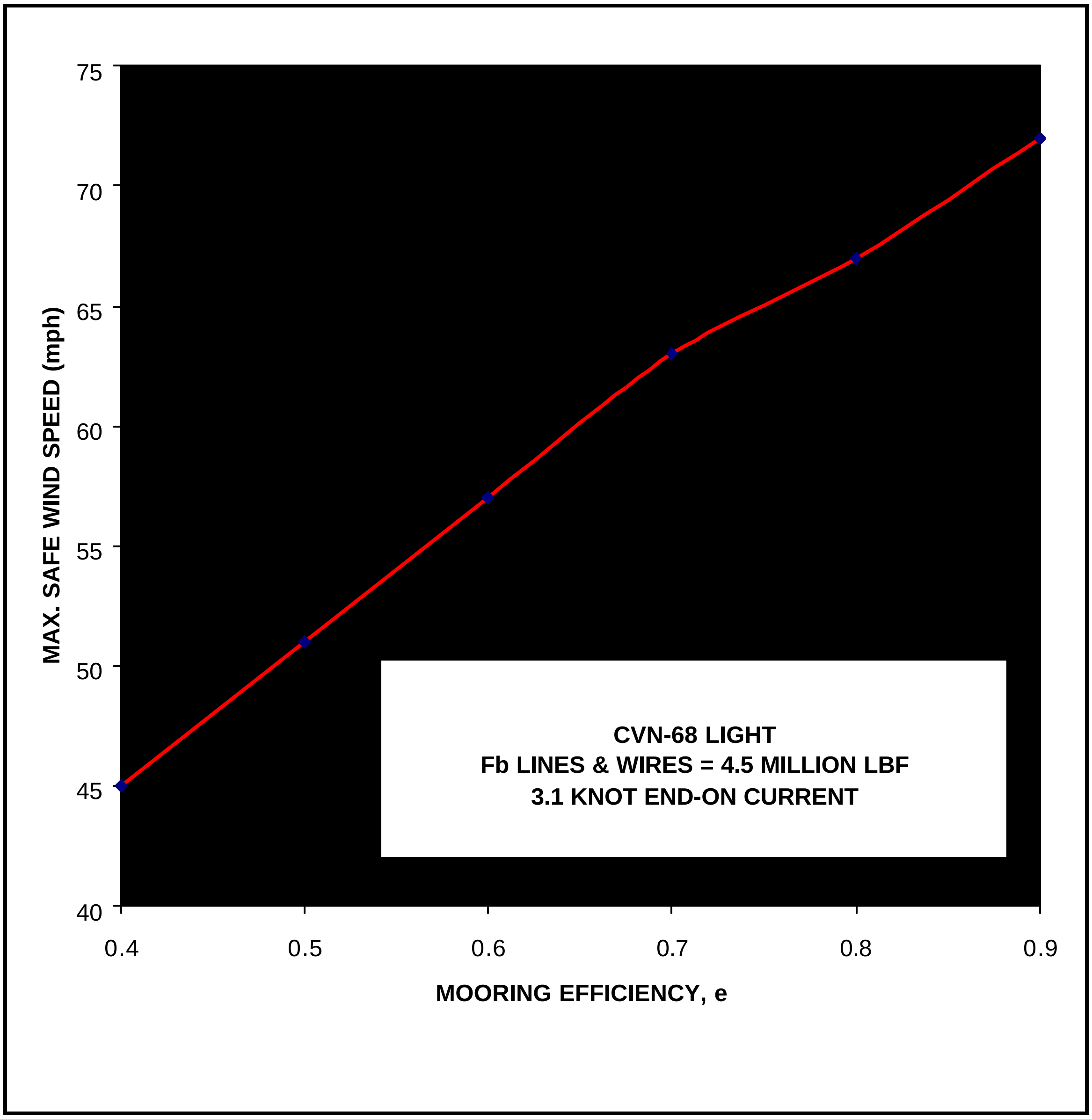


Figure 4.1 MAXIMUM SAFE WIND SPEED FOR A MOORED CVN-68 LIGHT USING SHIP'S LINES AND WIRE ROPES

4.2 AIRCRAFT CARRIER BREASTING MOORING

The broadside wind forces and moments on a CVN-68 are very high in 110 mph design conditions, due to the large exposed area of the ship. The use of mooring efficiency shows that a breasting system is needed toward the bow and another system towards the stern. Methods in W. Seelig, NFESC TR-6005-OCN, 1997 show that bow and stern breasting systems need to have an ultimate capacity of approximately 4 million pounds each and a working capacity of 1 300 kips each. The lack of adequate mooring fittings on the ships and very high loads suggests that mooring lines alone would be a poor choice and be a very expensive method of providing breasting of the CVN-68 in 110 mph winds.

Chain would appear to be a good method of providing aircraft carrier breasting, because the ship already has an anchor system on the bow. Chain also has the following advantages:

- Chain can have very high working loads
- Chain is durable
- Chain works well in dynamic situations
- Chain has excellent experience
- Chain is proof tested
- Chain is easy to inspect, and
- Chain is relatively inexpensive.

The ship's 4.75-inch chain has a new break strength of 2 550 kips. The working strength of this chain is 2 550/3 = 850 kips using a factor of safety of 3 and 2 550/4 = 638 kips with a factor of safety of 4. The breasting mooring on the bow and stern each need a working capacity of approximately 1 300 kips, so two 4.75-inch chains are needed on the bow and two on the stern.

One method of meeting this requirement on the bow would be to remove the ship's starboard anchor. The ship's starboard chain would then be joined to a chain pre-installed at the site. A second chain at the site would also be picked up and secured at the bow.

In the mean time, the ship's port anchor should be put out as a safety measure.

Two additional anchor legs are required on the stern. There is currently no structure on the ship for securing these chains to the ship. Therefore, two padeyes need to be put on the stern.

A cost effective way to anchor the chains would be driven plate anchors (J. Forrest et. al. NFESC TR-2039-OCN of 1995). These anchors are connected to the chains, driven in and then proof tested, as shown in Figures 4.2 and 4.3. Soil borings taken to support wharf construction (SOUTHNAVFACENGCOM drawings 5084481 through 84) show there is a variety of sediment types at the site. Some of the major layers are sand. This suggests that an anchor approximately 4 ft wide x 8 ft long driven in approximately 70 feet could provide the required holding capacity.

4.3 PROPOSED CONCEPT

The proposed concept (Figure 4.4) includes:

(a) Four driven plate anchors with 4.75-inch chain for mooring breasting,

(b) A new storm bollard on the wharf,

(c) Upgrading of selected bollards on the wharf face, and

(d) 70-foot camels to offset the ship from the wharf, so elevators do not interfere with wharf operations.

The port bow anchor is put under-foot for safety. The starboard bow anchor is removed and the ship's chain joined with anchor leg #2. Anchor leg #1 is secured to the bow through the anchor hawse or bullnose (providing adequate mooring hardware is on the forecastle deck to accommodate these chains).

The two stern anchor legs #3 and #4 would be joined to chain pigtails attached to the ship's stern with padeyes. These padeyes would have to be added to the ship.

Mooring lines and / or wire ropes would provide spring and additional breasting lines.

The existing marine fenders on the face of the wharf would have to be removed in the area of the camels.

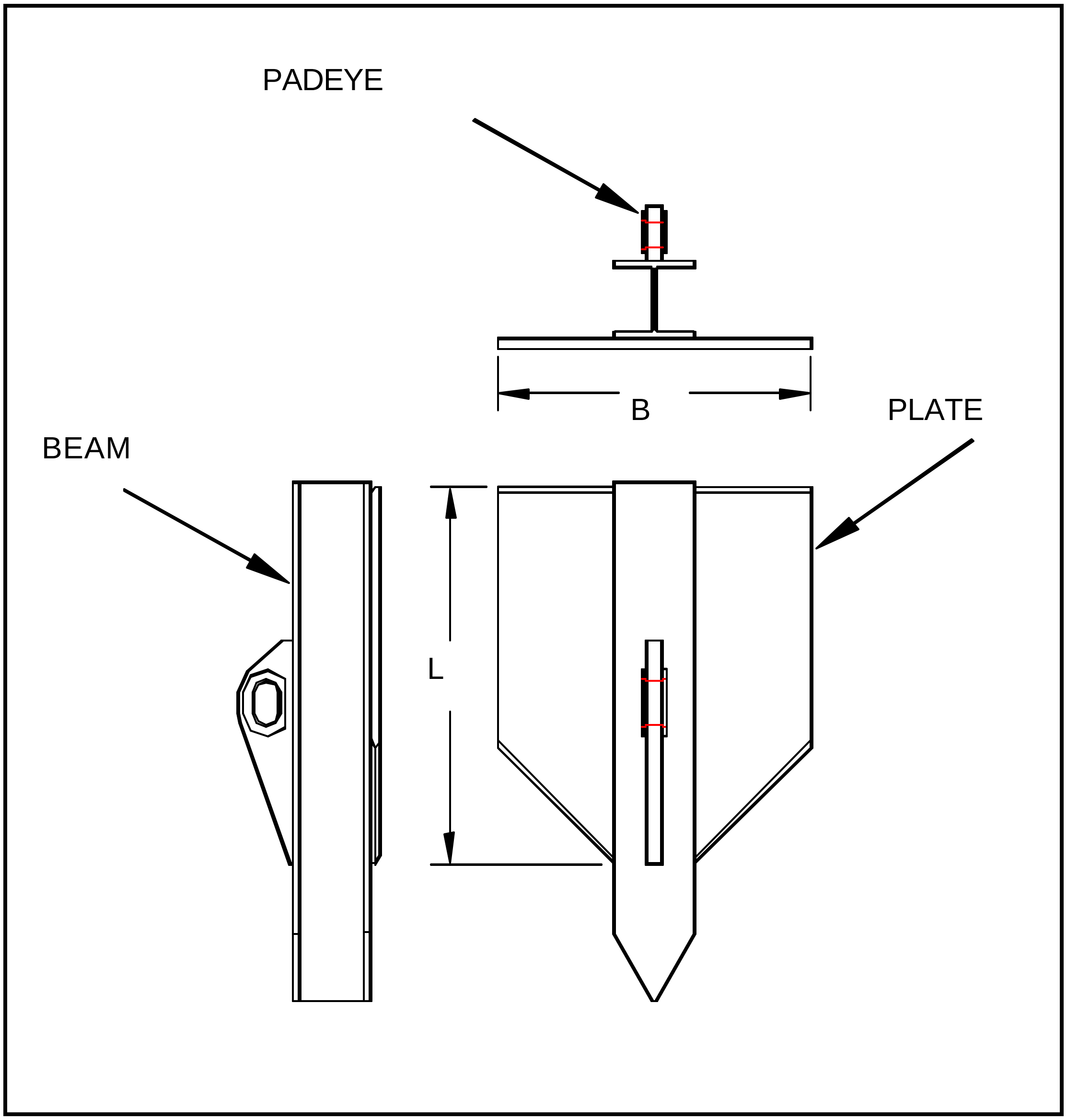


Figure 4.2 A DRIVEN PLATE ANCHOR

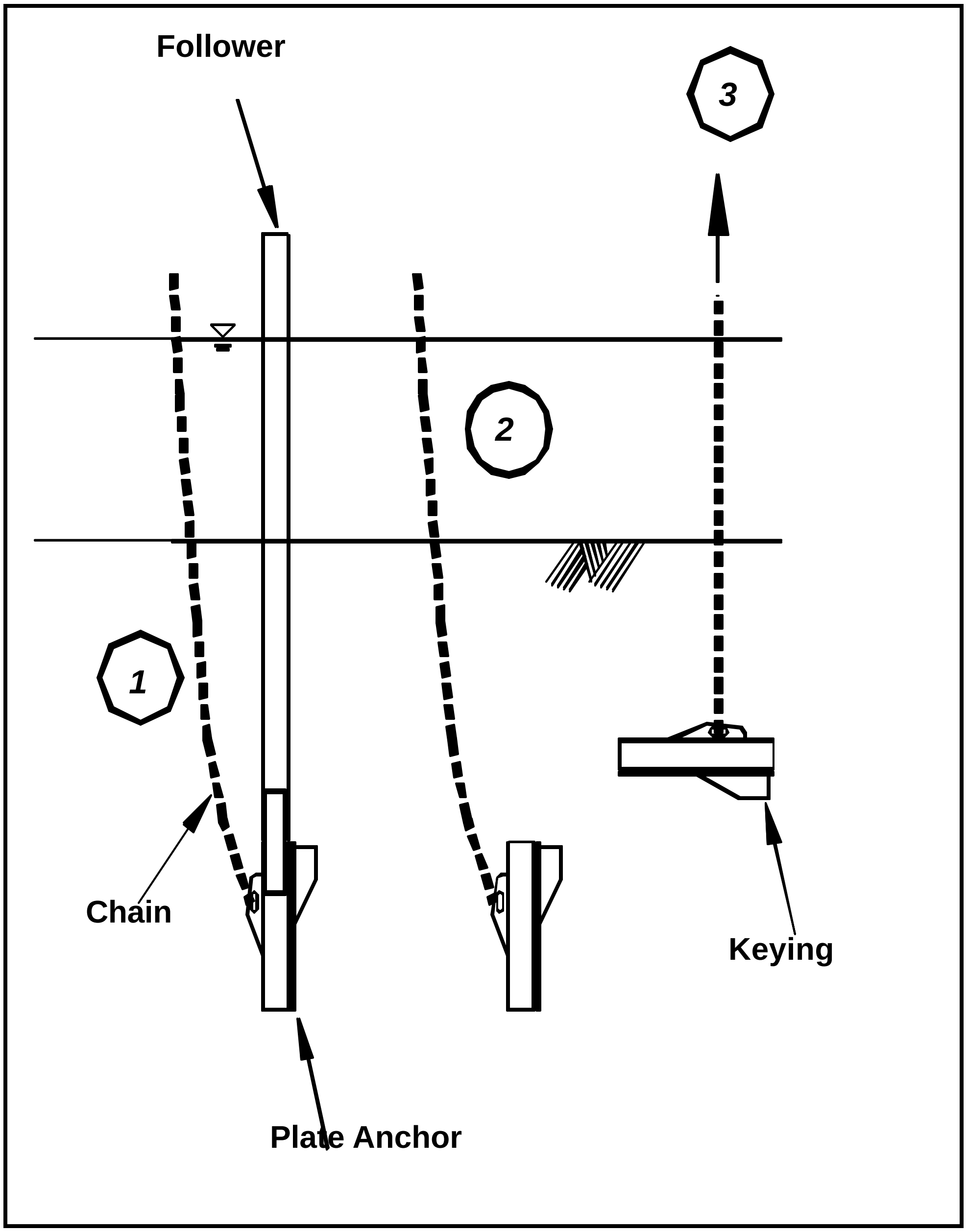


Figure 4.3 PLATE ANCHOR INSTALLATION

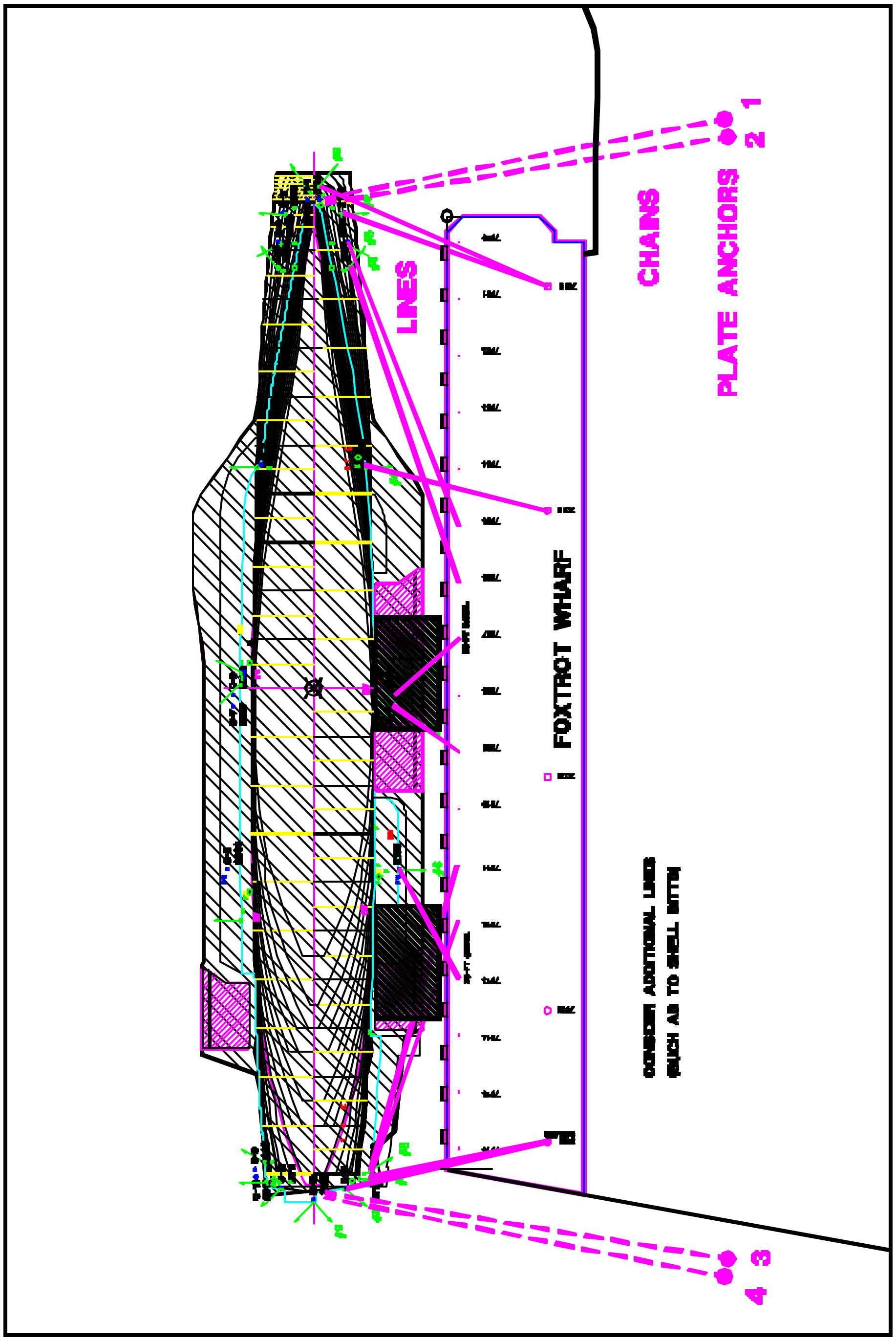


Figure 4.4 *MOORING SERVICE TYPE III* CONCEPT FOR A CVN-68 AT WHARF FOXTROT (NAVSTA MAYPORT)

5.0 PRELIMINARY COST ESTIMATE

A preliminary cost estimate of unit items is given in Table 5.1 and a summary given in Table 5.2. This estimate is based on extensive marine experience, including installation of several hundred driven plate anchors over the past five years.

Table 5.1 PRELIMINARY COST ESTIMATE FOR VARIOUS ITEMS

***MOORING SERVICE TYPE III* CONCEPT FOR**
A CVN-68 AT WHARF FOXTROT (NAVSTA MAYPORT)

ITEM	*DESCRIPTION*	*UNIT COST*	*NUM*	*COST*	*TOTAL*
	DESIGN				
1	MOORING DESIGN	$100,000	1	$100,000	
2	SOILS & DRIVING EVAL.	$20,000	1	$20,000	$120,000
	MATERIALS				
2	PLATE ANCHORS	$20,000	4	$80,000	
3	CHAIN SHOTS, 4.75-INCH	$35,000	28	$980,000	
4	CHAIN JOINING LINKS	$6,000	32	$192,000	
5	BOLLARDS	$10,000	5	$50,000	
6	SINKER ASSEMBLIES	$15,000	8	$120,000	$1,422,000
	INSTALLATION				
7	MOBILIZE INST. EQUIPMENT	$200,000	1	$200,000	
8	FOLLOWER	$50,000	1	$50,000	
9	DAY RATE (RENTAL/LABOR)	$25,000	10	$250,000	
10	STORM BOLLARD INST.	$300,000	1	$300,000	
11	BITT UPGRADE	$50,000	4	$200,000	
12	CONST. MATERIALS	$50,000	1	$50,000	
13	PROOF LOAD ANCHORS	$250,000	1	$250,000	
14	QA/QC	$25,000	1	$25,000	$1,325,000
	OTHER				
15	SHIP MOD DESIGN	?			
16	SHIP PADEYES	?			
17	STORM LINES	?			
18	CAMELS	?			

Table 5.2 PRELIMINARY FACILITIES COST ESTIMATE

***MOORING SERVICE TYPE III* CONCEPT FOR**
A CVN-68 AT WHARF FOXTROT (NAVSTA MAYPORT)*

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DESIGN	$120,000
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Sub-Total=	$2,867,000
Contingency (15%)	$430,000
Total (rounded) =	$3,300,000

* does not include utilities, dredging, etc.

6.0 SUMMARY

A concept design is developed to provide *Mooring Service Type III* for a CVN-68 at NAVSTA Mayport, FL. The design criteria used are winds of 110 mph, currents of 3.1 knots and water levels from -3.2 to +7.5 feet. In this development we conclude:

- Existing Wharf FOXTROT has adequate length,
- The facilities can be upgraded at a cost of approximately $3.3 M to provide this mooring service,
- Ship's lines alone cannot safely secure the ship, due to inadequate mooring fittings on the ship,
- Two 4.75-inch mooring chains are needed on the ship's bow and stern to moor the ship in the breasting direction, and
- Two padeyes are required on the stern to connect the stern chains to the ship.

The following steps would be used to provide *Mooring Service Type III* for a CVN-68 at NAVSTA Mayport:

1. Wharf is upgraded and driven plate anchors are proof tested.
2. Padeyes are added to the ship's stern.
3. The ship berths at FOXTROT, puts out standard mooring lines and the port anchor under-foot.
4. The starboard anchor is removed and the ship's chain is connected to one of the ground legs.
5. The other bow chain leg is secured to the ship.
6. Chain pigtails are added to the stern padeyes and these are connected to the two stern chains.
7. Extra storm lines are added in case a hurricane threatens the site.
8. Chains would have to be pulled out of the water, in case of dredging. Dredging would have to be done carefully around legs #3 and #4, where they enter the seafloor.

The storm chains #1 through #4 would only have to be used during ship repair, when the ship is unable to get underway. This above process is reversed prior to the ship exiting port.

Note that tugs will be of very little use in holding a CVN in hurricane condtions. The broadside wind force is over 2.3 million pounds in design conditions and there are wind moments that also need to be resisted. The maximum bollard pull of the existing three commercial tugs at NAVSTA Mayport is only a small fraction of the hurricane wind force on a CVN. In addition, since the tugs are commercial it is highly unlikely that the owners would consider risking their tugs. The Mayport harbor pilot reports that previous attempts to use tugs to assist in heavy weather mooring did not go well. Full scale operations showed that it is very difficult for tugs to work effectively in high storm conditions. Note also that there is no place that a CVN could be "packed-in" at Mayport and that only a small number of support craft, such as YCs, would be available for packing.

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APPENDIX A. SHIP INFORMATION

Various ship information from the NAVFAC Ship's Database is provided in this appendix, along with computed environmental forces and moments on the ship (using methods in MIL-HDBK-1026/4 'Mooring Design', 1998 draft).

CALCULATE VESSEL WIND LOADS

W-CVN683.MCD
Clarke/Seelig
15 Jan 1999

$knot \equiv \frac{6080 \cdot ft}{3600 \cdot sec}$ $kip \equiv 1000 \cdot lbf$

CVN-68 T=33.5 ft
One Third Stores

This is a Mathcad file used to calculate wind loading on a single ship using the methods of DOD Design Manual DM.

ENTER REQUIRED ENVIRONMENTAL INPUT DATA

$\rho_{\alpha} := 1.221 \cdot \frac{kg}{m^3}$ mass density of air

$h_R := 10 \cdot m$ reference wind height

$v_R := 70 \cdot mph$ $v_R = 31.29 \cdot m \cdot sec^{-1}$ Wind speed at reference height

ENTER REQUIRED VESSEL DATA FOR WIND FORCE CALCULATIONS

$Lwl := 1056 \cdot ft$ $Lwl = 321.87 \cdot m$ Waterline length of ship (to calculate avg. height of the hull)

$A_S := 4732 \cdot ft^2$ $A_S = 439.62 \cdot m^2$ Longitudinal wind area of superstructure

$A_H := 79418 \cdot ft^2$ $A_H = 7378.17 \cdot m^2$ Longitudinal wind area of hull $A_Y := A_S + A_H$

$A_Y = 84150 \cdot ft^2$ $A_Y = 7817.79 \cdot m^2$ Longitudinal wind area of ship

$h_S := 121.6 \cdot ft$ $h_S = 37.06 \cdot m$ Average height of superstructure above waterline

$h_H := \frac{A_H}{Lwl}$ $h_H = 22.92 \cdot m$ Average height of hull above waterline

$h_H = 75.21 \cdot ft$

$A_X := 15350 \cdot ft^2$ $A_X = 1426.06 \cdot m^2$ Transverse wind area of ship

$L := 1115 \cdot ft$ $L = 339.85 \cdot m$ Overall length of vessel (for moment calculations)

CALCULATE THE TRANSVERSE WIND FORCES

Determine the empirical coefficient

To calculate the lateral wind-force drag coefficient, first determine the appropriate empirical coefficient as described in Section 4.3.1 using Table 4.2. Table 4.2 is also included below.

$C := 0.82$ Empirical coefficient, from Table 4.2

SHIP	C	NOTES
Hull dominated	0.82	aircraft carriers, drydocks
Typical	0.92	ships with moderate superstructure
Extensive superstructure	1.02	destroyers, cruisers

Determine the transverse wind-force drag coefficient

$$C_{yw} := C \cdot \frac{\left[\left[\frac{0.5 \cdot (h_S + h_H)}{h_R}\right]^{\frac{2}{7}} \cdot A_S + \left(\frac{0.5 \cdot h_H}{h_R}\right)^{\frac{2}{7}} \cdot A_H\right]}{A_Y}$$

Equation (4-2)

$C_{yw} = 0.868$

Transverse wind-force drag coefficient

Develop the transverse wind shape function

$i := 0 .. 12$ $\qquad \theta_{\omega_i} := i \cdot 15 \cdot deg$

this simply sets angle increments in ten degrees from 0 to 180.

$$f_{ywtheta_i} := \frac{\left(\sin\left(\theta_{\omega_i}\right) - \frac{\sin\left(5 \cdot \theta_{\omega_i}\right)}{20}\right)}{\left(1 - \frac{1}{20}\right)}$$

this is the shape function for the lateral load
Eq (4-3)

Develop the transverse wind-force coefficients

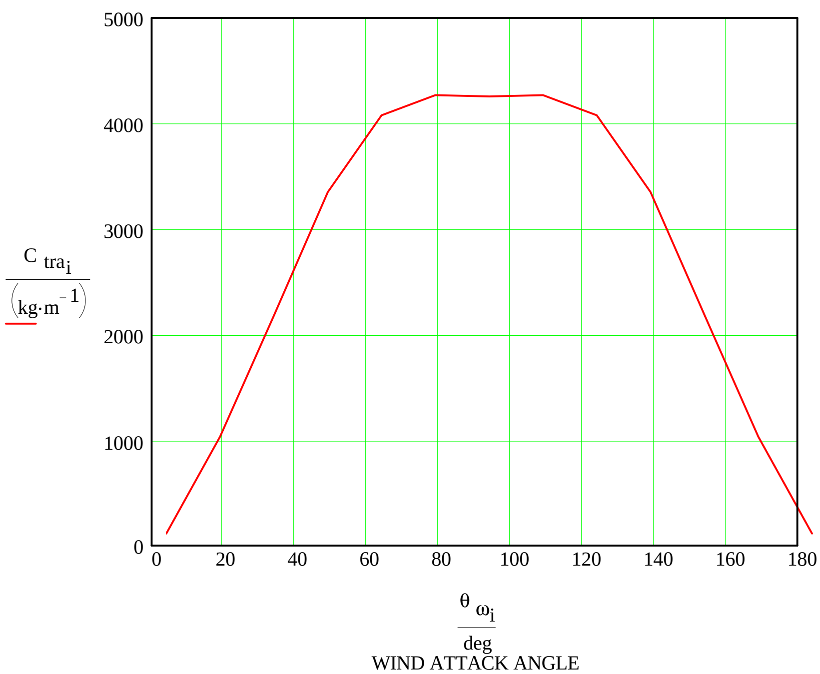
The transverse wind-force coefficient step is used if the user's analysis program calculates the wind forces in terms of the wind speed squared multiplied by a load coefficient (i.e.. Atkiins Quantitative Wave Analysis System, or AQWA, by W. S. Atkins).

$$C_{tra_i} := 0.5 \cdot \rho_{\alpha} \cdot A_Y \cdot C_{yw} \cdot f_{ywtheta_i}$$

this is Eq (4-1), without wind speed terms

$\frac{\theta_{\omega_i}}{deg}$	$\frac{C_{tra_i}}{(kg \cdot m^{-1})}$
0	0
15	917.79
30	2070.79
45	3236.81
60	3964.27
75	4154.6
90	4141.59
105	4154.6
120	3964.27
135	3236.81
150	2070.79
165	917.79
180	$-2.7 \cdot 10^{-12}$

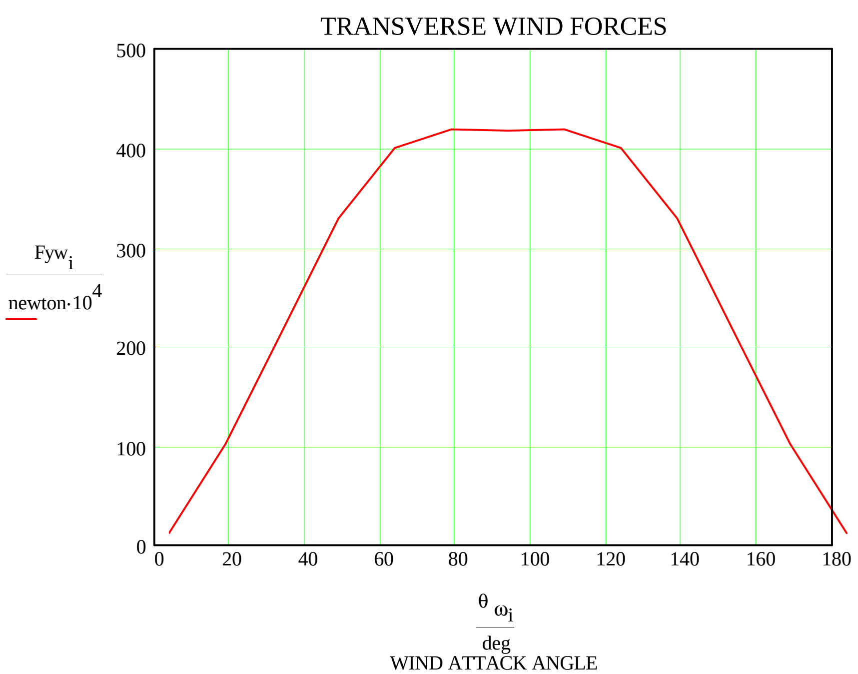
Graph of transverse wind force coefficients



Calculate the transverse wind forces

$Fyw_i := C_{tra_i} \cdot v_R^2$ Transverse wind force

$\frac{\theta_{\omega_i}}{deg}$	$\frac{Fyw_i}{newton \cdot 10^4}$
0	0
15	89.87
30	202.78
45	316.96
60	388.2
75	406.83
90	405.56
105	406.83
120	388.2
135	316.96
150	202.78
165	89.87
180	-0



Maximum lateral wind force

$\max(Fyw) = 4.06835 \cdot 10^{6} \cdot newton$

CALCULATE THE LONGITUDINAL WIND FORCES

Develop the longitudinal wind-force shape function

The longitudinal wind force shape will depend on whether the vessel analyzed is Case 1 or Case II and the wind angle that produces no net longitudinal wind force. Recommended values for this angle of no net longitudinal wind force is provided in Table 4.3. A copy is provided below.

LOCATION OF SUPERSTRUCTURE	θ_x
Just Forward of midships	100°
On midships	90°
Aft of midships (tankers)	80°
Warships	70°
Hull dominated	60°

$\theta_x := 60 \cdot deg$ Incident wind angle producing no net longitudinal force

Case One: Single Distinct Superstructure

$$\phi_i := \mathrm{if}\left[\theta_{\omega_i} < \theta_x, \frac{90 \cdot deg}{\theta_x} \cdot \theta_{\omega_i}, \frac{90 \cdot deg}{(180 \cdot deg - \theta_x)} \cdot \left(\theta_{\omega_i} - \theta_x\right) + 90 \cdot deg\right]$$

Angle for shape function.
Eq (4-5a&b)

$$f1_{xwtheta_i} := \cos\left(\phi_i\right)$$

Longitudinal shape function.
This is DM Eq(4-5)

Case Two: Distributed Superstructure

$$\gamma_i := \mathrm{if}\left[\theta_{\omega_i} < \theta_x, \frac{90 \cdot deg}{\theta_x} \cdot \theta_{\omega_i} + 90 \cdot deg, \frac{90 \cdot deg}{(180 \cdot deg - \theta_x)} \cdot \theta_{\omega_i} + \left[180 \cdot deg - \frac{\left(90 \cdot deg \cdot \theta_x\right)}{(180 \cdot deg - \theta_x)}\right]\right]$$

Angle for shape function.
Eq(4-6a&b)

$$f2_{xwtheta_i} := \frac{\left(\sin\left(\gamma_i\right) - \frac{\sin\left(5 \cdot \gamma_i\right)}{10}\right)}{\left(1 - \frac{1}{10}\right)}$$

Longitudinal shape function.
Eq(4-6)

Develop the longitudinal wind force coefficients

The longitudinal wind force coefficients will depend on whether the vessel analyzed is Case 1 or Case II and whether the loading is bow or stern loading. Longitudinal wind force drag coefficients for bow or wind loading are provided in Table 4.3. A copy is provided below.

VESSEL TYPE	C_{xwB}	C_{xwS}
Hull dominated (aircraft carriers, submarines, passenger liners)	0.40	0.40
Normal *	0.70	0.60
Center-Island Tankers *	0.80	0.60
Significant Superstructure (destroyers, cruisers)	0.70	0.80

*An adjustment of up to +0.10 to C_{xwB} and C_{xwS} should be made to account for significant cargo or cluttered decks.

$C_{xwB} := 0.4$ Drag force coefficient for bow wind loading

$C_{xwS} := 0.4$ Drag coefficient for stern wind loading

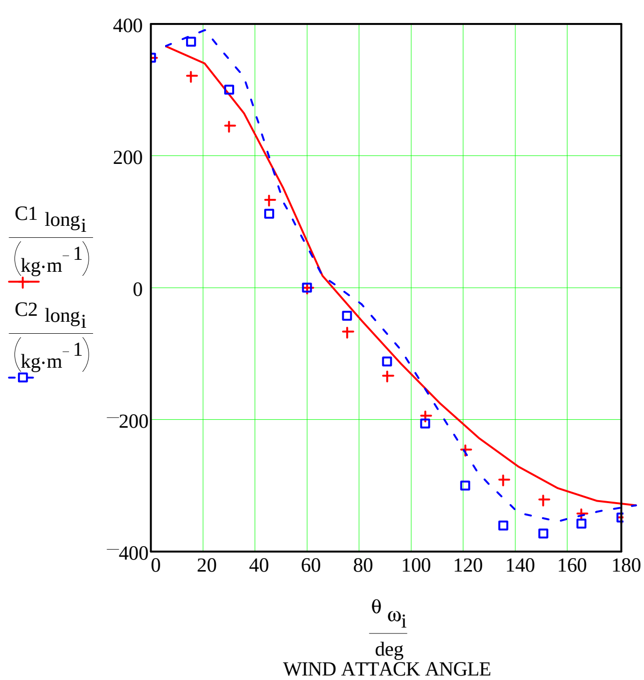
$$C1_{long_i} := 0.5\cdot\rho_\alpha\cdot A_X\cdot \mathrm{if}\left(\theta_{\omega_i} < \theta_x, C_{xwS}, C_{xwB}\right)\cdot f1_{xwtheta_i}$$

$$C2_{long_i} := 0.5\cdot\rho_\alpha\cdot A_X\cdot \mathrm{if}\left(\theta_{\omega_i} < \theta_x, C_{xwS}, C_{xwB}\right)\cdot f2_{xwtheta_i}$$

this is Eq(4-4), without wind speed terms. The negative sign is used to insure loads are consistent with the local coordinate system as shown in Figure 4.2.

$\frac{\theta_{\omega_i}}{deg}$	$\frac{C1_{long_i}}{(kg\cdot m^{-1})}$	$\frac{C2_{long_i}}{(kg\cdot m^{-1})}$
0	348.24	348.24
15	321.74	372.29
30	246.25	300.97
45	133.27	112.33
60	$-1.33\cdot10^{-13}$	$-1.83\cdot10^{-13}$
75	-67.94	-43.32
90	-133.27	-112.33
105	-193.47	-207.42
120	-246.25	-300.97
135	-289.55	-359.68
150	-321.74	-372.29
165	-341.55	-358.01
180	-348.24	-348.24

Graph of longitudinal wind force coefficients



Calculate the longitudinal wind forces

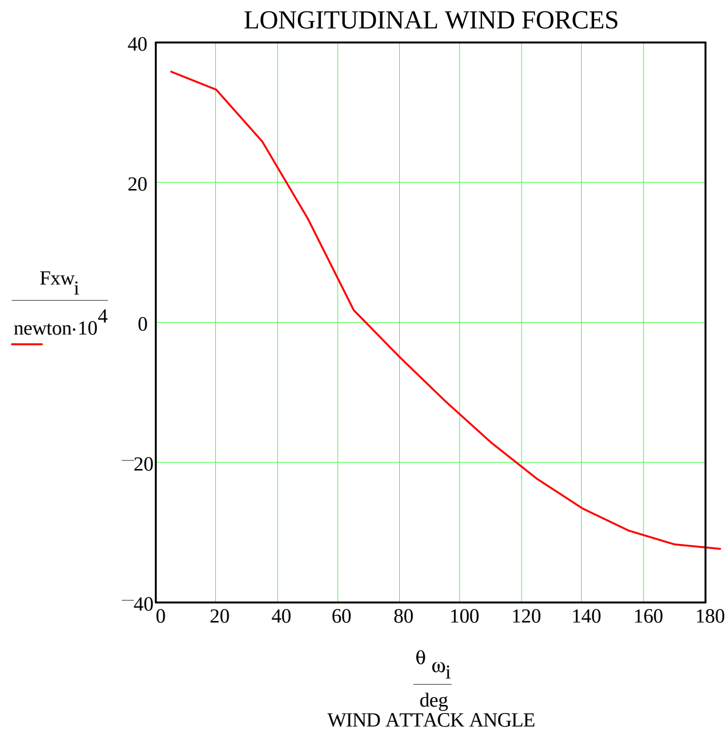
Superstructure := 1   Set superstructure "switch" to 1 for Case 1 and 2 for Case II.

For calculation of the longitudinal wind force, C1long is the shape function used if the user input term "Superstructure" in the input data block is set to 1. Otherwise the term C2long is used, a so-called "humped" distribution.

$$C_{long_i} := \mathrm{if}\left(\mathrm{Superstructure} = 1, C1_{long_i}, C2_{long_i}\right)$$

$$Fxw_i := C_{long_i} \cdot v_R^{\,2}$$ Longitudinal wind force

$\dfrac{\theta_{\omega_i}}{deg}$	$\dfrac{Fxw_i}{newton \cdot 10^4}$
0	34.1
15	31.51
30	24.11
45	13.05
60	$-1.31 \cdot 10^{-14}$
75	-6.65
90	-13.05
105	-18.95
120	-24.11
135	-28.35
150	-31.51
165	-33.45
180	-34.1



Maximum longitudinal wind force

$\max(Fxw) = 3 \cdot 10^{5} \cdot newton$

CALCULATE THE YAW WIND MOMENTS

Develop yaw wind normalized moment coefficient

The static wind yaw moment is defined as the product of the associated transverse wind force and its distance from the vessel's center of gravity. A plot of the yaw moment coefficients will produce a sinusoidal shaped curve that may have different positive and negative peaks. The zero moment angle or the point where the curve crosses the x-axis may be different than 90^0. Using Table 4.5, input the positive and negative peaks and the the zero moment angle for the type vessel analyzed A copy of Table 4.5 is provided below

SHIP TYPE	Zero Moment Angle (θ_z)	Negative Peak (a1)	Positive Peak (a2)	NOTES
Liner	80	0.075	0.14	
Carrier	90	0.068	0.072	
Tanker	95	0.077	0.07	Center island w/ cluttered deck
Tanker	100	0.085	0.04	Center island w/ trim deck
Cruiser	90	0.064	0.05	
Destroyer	68	0.02	0.12	
Others:	130	0.13	0.025	stern superstructure
	102	0.096	0.029	aft midships superstructure
	90	0.1	0.1	midships superstructure
	75	0.03	0.05	forward midships superstructure
	105	0.18	0.12	bow superstructure

EDIT USER INPUT TERMS

$a1 := 0.068$ This is the negative peak taken from Table 4.5, **must enter into equation as a positive value**

$a2 := 0.072$ This is the positive peak taken from Table 4.5,

$\theta z := 90 \cdot deg$ This is the zero moment angle taken from Table 4.5

$\theta 1 := 90 \cdot deg - \theta z$ **this is an angle used in the empirical equation below and should not be edited by the user**

$$\lambda := \frac{180 \cdot deg}{(180 \cdot deg - \theta z)}$$ Eq(4-8b)

$$cxyw_i := \mathrm{if}\left[\theta_{\omega_i} \le \theta z, -a1 \cdot \sin\left[\theta_{\omega_i} \cdot \frac{(180 \cdot deg)}{\theta z}\right], a2 \cdot \sin\left[\left(\theta_{\omega_i} - \theta z\right) \cdot \lambda\right]\right]$$ Eq(4-8)

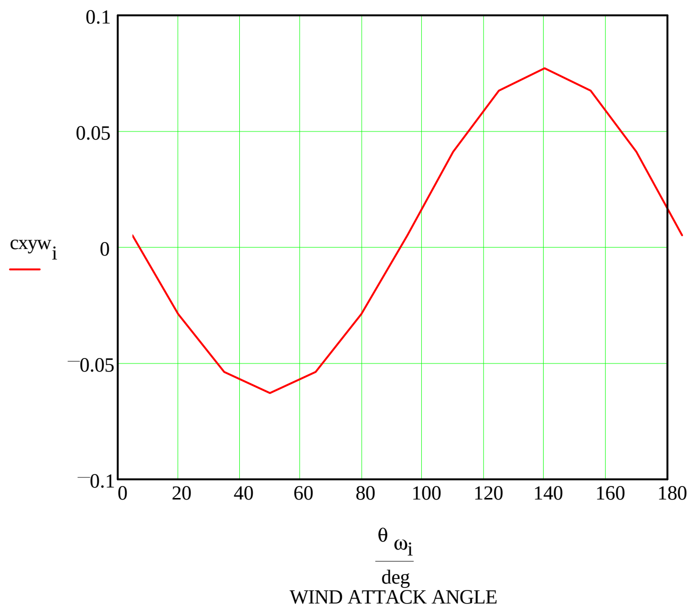
Calculate the yaw wind moment coefficients

$Cxyw_i := .5 \cdot \rho_{\alpha} \cdot A_Y \cdot L \cdot cxyw_i$

this is Eq(4-7) without the wind speed. The negative sign is to insure moments are consistent with the local coordinate system as shown in Figure 4.2

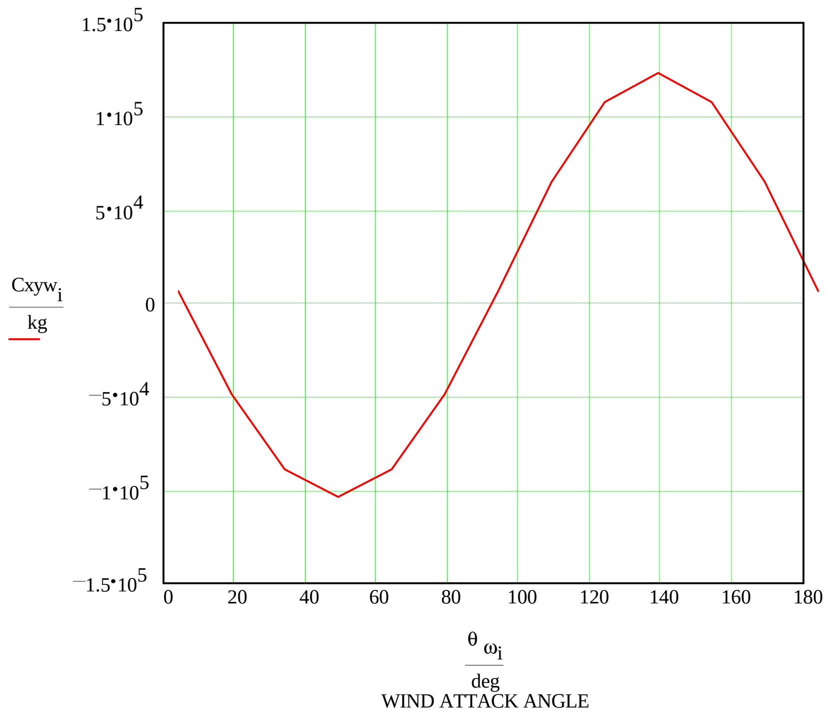
$\frac{\theta \omega_i}{deg}$	$cxyw_i$
0	0
15	-0.034
30	-0.0589
45	-0.068
60	-0.0589
75	-0.034
90	0
105	0.036
120	0.0624
135	0.072
150	0.0624
165	0.036
180	0

Graph of normalized wind yaw moment coefficient



$\frac{\theta \omega_i}{deg}$	$\frac{Cxyw_i}{kg}$
0	0
15	-55149.1
30	-95521.05
45	$-1.1 \cdot 10^{5}$
60	-95521.05
75	-55149.1
90	$8.45 \cdot 10^{-11}$
105	58393.17
120	$1.01 \cdot 10^{5}$
135	$1.17 \cdot 10^{5}$
150	$1.01 \cdot 10^{5}$
165	58393.17
180	$-8.94 \cdot 10^{-11}$

Graph of wind yaw moment coefficient

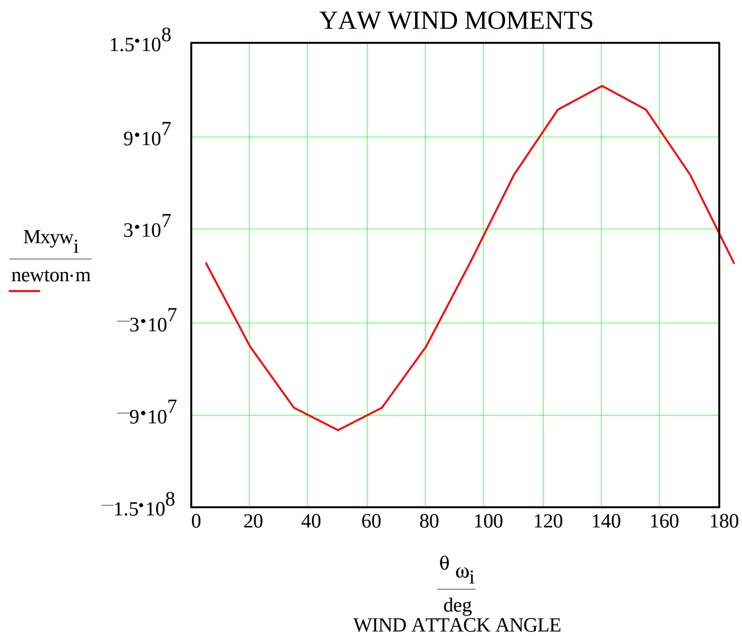


Calculate the yaw wind moments

$$Mxyw_i := Cxyw_i \cdot v_R^{\,2}$$

$\frac{\theta_{\omega_i}}{deg}$	$\frac{Mxyw_i}{newton \cdot m \cdot 10^7}$
0	0
15	-5.4
30	-9.35
45	-10.8
60	-9.35
75	-5.4
90	$8.27 \cdot 10^{-15}$
105	5.72
120	9.9
135	11.44
150	9.9
165	5.72
180	$-8.76 \cdot 10^{-15}$

Yaw wind moment

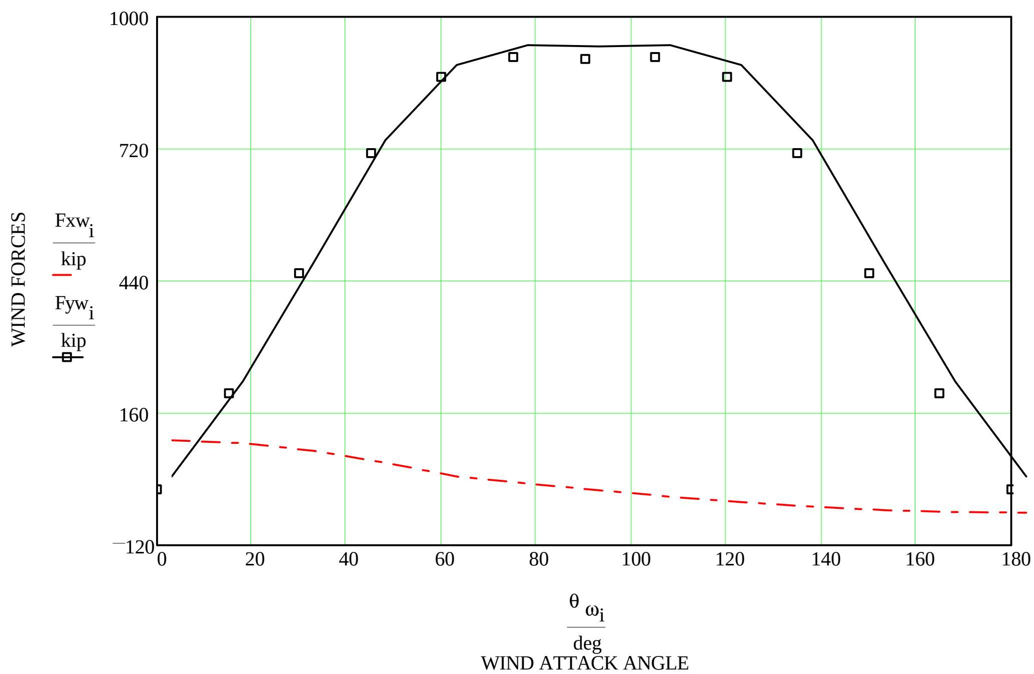


Maximum wind yaw moment

$$\max(Mxyw) = 1.14362 \cdot 10^{8} \cdot newton \cdot m$$

Plot of wind forces and moments in US units

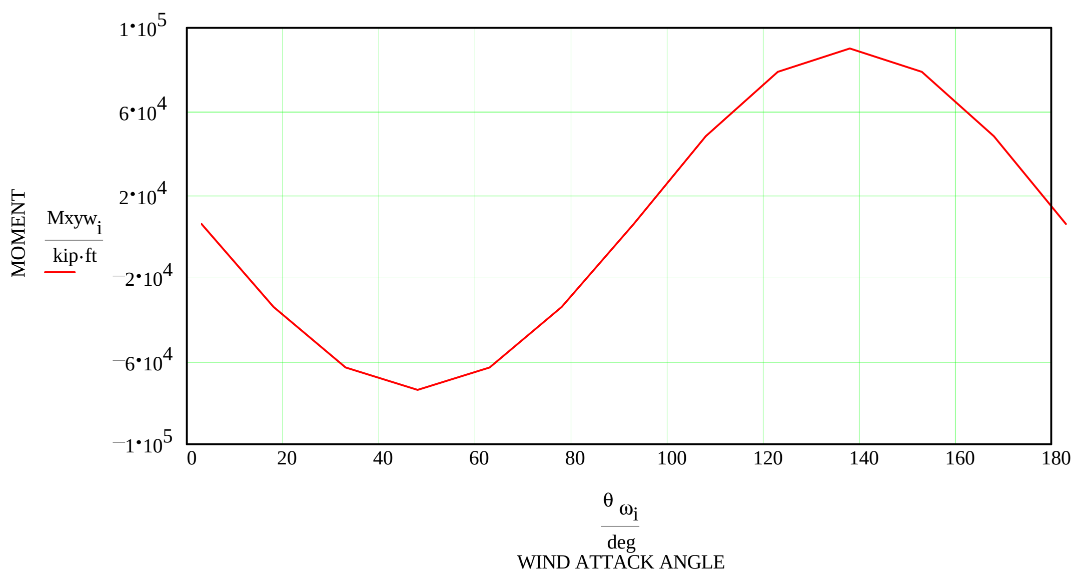
PLOT TRANSVERSE & LONGITUDINAL WIND FORCES



$\max(Fyw) = 914.6 \cdot kip$

$\max(Fxw) = 76.66 \cdot kip$

PLOT WIND YAW MOMENTS

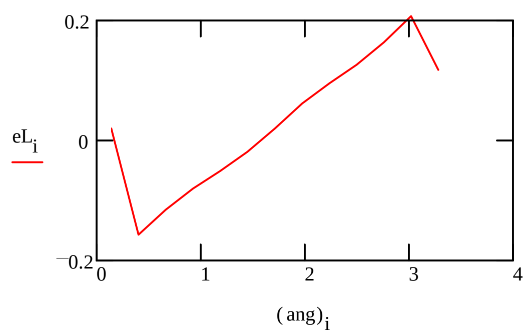


$\max(Mxyw) = 84348.9 \cdot kip \cdot ft$

$$eL_i := \frac{Mxyw_i}{\left(L \cdot Fyw_i\right)} \qquad facty_i := \frac{C\ tra_i}{C\ tra_6}$$

$$ang_i := i \cdot 15 \cdot deg$$

$\frac{\theta\ \omega_i}{deg}$	eL_i	$facty_i$
0	0	0
15	-0.1768	0.2216
30	-0.1357	0.5
45	-0.1003	0.7815
60	-0.0709	0.9572
75	-0.0391	1.0031
90	0	1
105	0.0414	1.0031
120	0.0751	0.9572
135	0.1062	0.7815
150	0.1437	0.5
165	0.1872	0.2216
180	0.0976	0



C-CVN683.MCD
Clarke/Seelig
15 Jan 1999

CALCULATE VESSEL CURRENT LOADS

This Mathcad file is used to develop current loads on the above vessel in a range of water depths, for a specified design current velocity.

CVN 68
One Third
Stores
T=33.5 ft

$longton \equiv 2240 \cdot lbf$

$knot \equiv 6080 \cdot \frac{ft}{3600 \cdot sec}$

$kip \equiv 1000 \cdot lbf$

ENTER ENVIRONMENTAL INPUT DATA

$i := 0..3$

Counter

$V_c := 2.0 \cdot knot \qquad V_c = 1.03 \cdot m \cdot sec^{-1}$ Current velocity

$d := \begin{bmatrix} 37.22 \\ 45 \\ 50 \\ 55 \end{bmatrix} \cdot ft$ Water depth increments

$\rho_\omega := 1026 \cdot \frac{kg}{m^3}$ Mass density of seawater (eg lb/cuft) at sea level

$\nu := 1.191 \cdot 10^{-6} \cdot \frac{m^2}{sec}$ Kinematic viscosity of seawater, in meters^2 per second based on 15^0 C salt water.

$\gamma_\omega := 10060 \cdot \frac{newton}{m^3}$ Unit weight density of seawater (eg lbf/cuft) at sea level

ENTER VESSEL DATA FOR CURRENT FORCE CALCULATIONS

$Lwl := 1056 \cdot ft \qquad Lwl = 321.869 \cdot m$ Vessel waterline length

$T := 33.5 \cdot ft \qquad T = 10.211 \cdot m$ Vessel average draft

$Td_i := \frac{T}{d_i}$

$B := 134 \cdot ft \qquad B = 40.843 \cdot m$ Vessel beam at loaded waterline

$D := 77780 \cdot longton \quad D = 7.75 \cdot 10^8 \cdot newton$ Vessel displacement

$mass := \frac{D}{g} \qquad mass = 79028145.989 \cdot kg$

$V := \frac{D}{\gamma_\omega} \qquad V = 77037.909 \cdot m^3$ Submerged volume of the vessel

CALCULATE THE TRANSVERSE CURRENT FORCES

Calculate the transverse current-force drag coefficient

$C_m := 0.9796$ — Midship coefficient

$A_m := C_m \cdot B \cdot T \qquad A_m = 408.534 \cdot m^2$ — Immersed cross-sectional area block of the ship at midsection

$\chi := \dfrac{Lwl^2 \cdot A_m}{B \cdot V} \qquad \chi = 13.451$ — Dimensionless ship parameter. This is DM equation xxxx.

$C_0 := 0.22 \cdot \chi^{0.5} \qquad C_0 = 0.807$ — Deep water drag coefficient where T/d = 0. This is DM equation xxxxx.

$C_1 := 3.2$ — Shallow water drag coefficient where T/d = 1.

Select the dimensionless exponent to fit the vessel analyzed from section 4.4.1. These choices are also provided below.

K = 2	wide range of ship and barge tests; most all of the physical model data available can be fit with this coefficient
K = 3	from a small number of tests on a fixed cargo ship and for a small number of tests on an old aircraft carrier, CVE-55
K = 5	from a small number of tests on an old submarine hull, SS-212

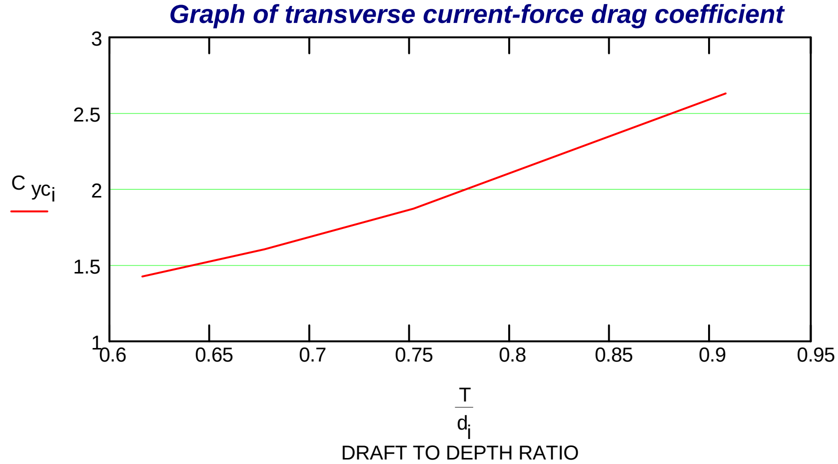
$k_{fac} := 3$ — Dimensionless exponent

$$C_{yc_i} := C_0 + (C_1 - C_0) \cdot \left(\left(\frac{T}{d_i}\right)\right)^{k_{fac}}$$

Estimate of the transverse current-force drag coefficient. This is DM equation xxxx.

$\frac{d_i}{ft}$	C_{yc_i}
37.22	2.552
45	1.794
50	1.527
55	1.348

Graph of transverse current-force drag coefficient



Develop the transverse current force coefficients

The transverse current-force coefficient step is used if the user's analysis program calculates the current forces in terms of the current speed squared multiplied by a load coefficient (i.e.. Atkiins Quantitative Wave Analysis System, or AQWA, by W. S. Atkins).

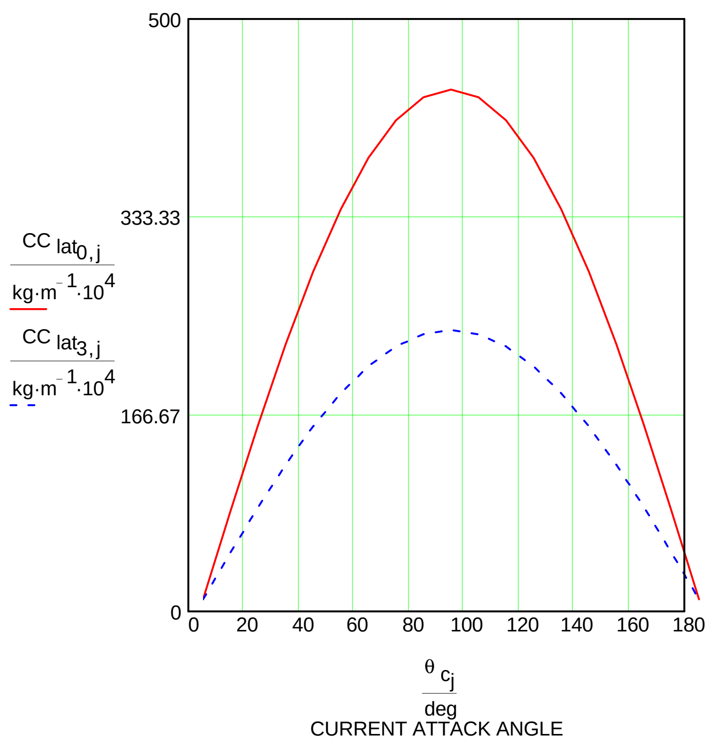
$j := 0..18$ Counter

$\theta_{c_j} := j \cdot 10 \cdot deg$ This simply sets angle increments in ten degrees from 0 to 180^0.

$CC_{lat_{i,j}} := 0.5 \cdot \rho_{\omega} \cdot Lwl \cdot T \cdot C_{yc_i} \cdot \sin\left(\theta_{c_j}\right)$ This is DM equation xxx without current speed terms

$\frac{\theta_{c_j}}{deg}$	$\frac{CC_{lat_{(0,j)}}}{kg \cdot m^{-1} \cdot 10^4}$	$\frac{CC_{lat_{(3,j)}}}{kg \cdot m^{-1} \cdot 10^4}$
0	0	0
10	74.7	39.5
20	147.1	77.7
30	215.1	113.6
40	276.5	146
50	329.6	174.1
60	372.6	196.8
70	404.3	213.5
80	423.7	223.8
90	430.2	227.2
100	423.7	223.8
110	404.3	213.5
120	372.6	196.8
130	329.6	174.1
140	276.5	146
150	215.1	113.6
160	147.1	77.7
170	74.7	39.5
180	$-3.3 \cdot 10^{-13}$	$-1.7 \cdot 10^{-13}$

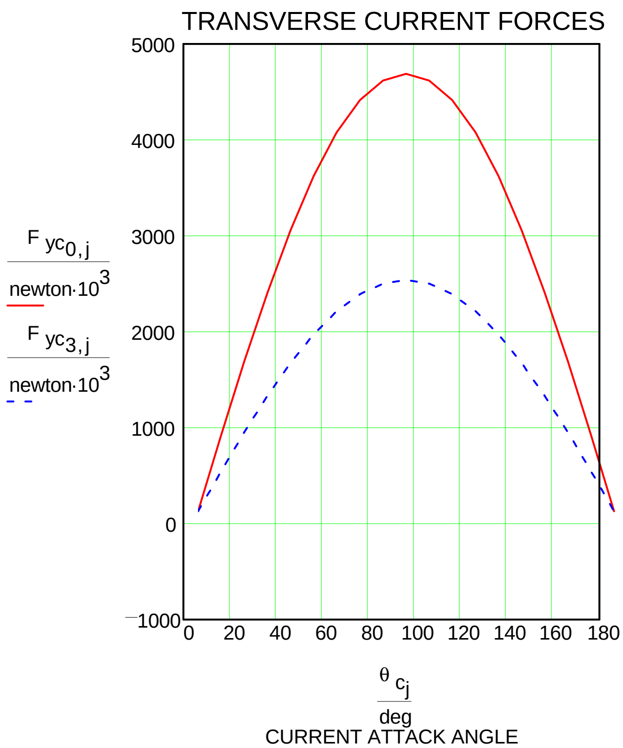
Graph of transverse current force coefficients



Calculate the transverse current forces

$F_{yc_{i,j}} := CC_{lat_{i,j}} \cdot V_c^{\ 2}$ Transverse current force

$\frac{\theta_{c_j}}{deg}$	$\frac{F_{yc_{0,j}}}{newton \cdot 10^3}$	$\frac{F_{yc_{3,j}}}{newton \cdot 10^3}$
0	0	0
10	791.88	418.21
20	1559.7	823.71
30	2280.13	1204.18
40	2931.28	1548.07
50	3493.37	1844.91
60	3949.31	2085.7
70	4285.25	2263.12
80	4490.99	2371.77
90	4560.27	2408.36
100	4490.99	2371.77
110	4285.25	2263.12
120	3949.31	2085.7
130	3493.37	1844.91
140	2931.28	1548.07
150	2280.13	1204.18
160	1559.7	823.71
170	791.88	418.21
180	$-3.49 \cdot 10^{-12}$	$-1.84 \cdot 10^{-12}$



$\max(F_{yc}) = 4560267.783 \cdot newton$

DEVELOP THE LONGITUDINAL CURRENT FORCES

Develop the longitudinal current force due to form drag factors

$Cxcb := 0.1$

Develop the longitudinal current force due to skin friction factors

$S := (1.7 \cdot T \cdot Lwl) + \left(\frac{D}{T \cdot \gamma_{\omega}}\right)$ Wetted Surface Area

$S = 13131.862 \cdot m^2$

$$Rn_j := \left| \frac{V_c \cdot Lwl \cdot \cos\left(\theta_{c_j}\right)}{\nu} \right|$$

Reynolds's Number

$$Rn_0 = 2.782 \cdot 10^8$$

$$Cxca_j := \frac{0.075}{\left(\log\left(Rn_j\right) - 2\right)^2}$$

Longitudinal tangential skin-friction coefficient

$$Cxca_0 = 0.00181$$

Develop the longitudinal current force due to propeller drag

$$Cprop := 1$$

Propeller-drag coefficient

Area ratios for various vessels are provided in Table xxx. A Copy of this table is provided below.

Vessel	Area Ratio, A_R
Destroyer	100
Cruiser	160
Carrier	125
Cargo	240
Tanker	270
Submarine	125

$$Ar := 125$$

Area ratio

$$Atpp := \frac{Lwl \cdot B}{Ar} \qquad Atpp = 1132.032 \cdot ft^2 \qquad Atpp = 105.169 \cdot m^2$$

Total projected propeller area

$$Ap := \frac{Atpp}{1.067 - 0.229} \qquad Ap = 1350.874 \cdot ft^2 \qquad Ap = 125.5 \cdot m^2$$

Propeller expanded blade area. This assumes the pitch to diameter ratio is 1.0. If not multiply the denominator term by the pitch to diameter ratio, or p/d.

Calculate the longitudinal current-force components

$$Fxform_j := 0.5 \cdot \rho_\omega \cdot V_c^2 \cdot B \cdot T \cdot Cxcb \cdot \cos\left(\theta_{c_j}\right)$$

Longitudinal current force due to form drag

$$Fxfric_j := 0.5 \cdot \rho_\omega \cdot V_c^2 \cdot S \cdot Cxca_j \cdot \cos\left(\theta_{c_j}\right)$$

Longitudinal current force due to skin friction

$$Fxprop_j := 0.5 \cdot \rho_\omega \cdot V_c^2 \cdot Ap \cdot Cprop \cdot \cos\left(\theta_{c_j}\right)$$

Longitudinal current force due to propeller drag

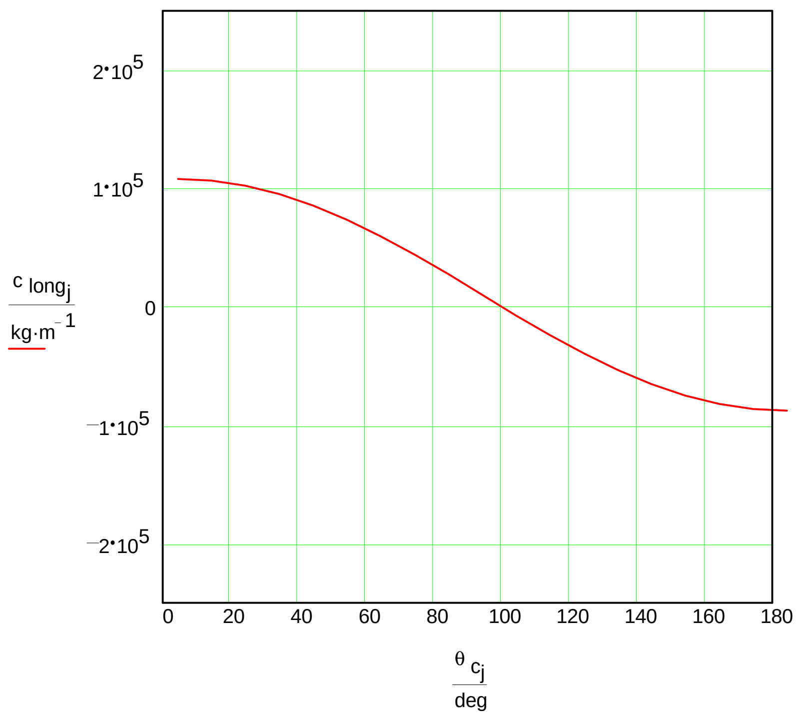
Develop the longitudinal current-force coefficients

$$c_{long_j} := \frac{Fxprop_j + Fxfric_j + Fxform_j}{V_c^{\,2}}$$

This is the summation of all longitudinal current force equations without current speed terms

$\frac{\theta_{c_j}}{deg}$	$\frac{c_{long_j}}{kg \cdot m^{-1} \cdot 10^2}$
0	979.42
10	964.78
20	921.31
30	850.27
40	753.72
50	634.43
60	495.82
70	341.72
80	176.1
90	-0
100	-176.1
110	-341.72
120	-495.82
130	-634.43
140	-753.72
150	-850.27
160	-921.31
170	-964.78
180	-979.42

Graph of longitudinal current force coefficients



PERCENTAGES OF LONGITUDINAL CURRENT FORCE

$Fxprop_{18} = -68242.362 \cdot newton$

$Fxprop_{18} = -15.341 \cdot kip$

$$PROP := \frac{\left(100 \cdot Fxprop_{18}\right) \cdot \left(V_c\right)^{-2}}{c_{long_{18}}}$$

$PROP = 65.735$

$Fxfric_{18} = -12895.265 \cdot newton$

$Fxfric_{18} = -2.899 \cdot kip$

$$FRIC := \frac{\left(100 \cdot Fxfric_{18}\right) \cdot \left(V_c\right)^{-2}}{c_{long_{18}}}$$

$FRIC = 12.421$

$Fxform_{18} = -22677.176 \cdot newton$

$Fxform_{18} = -5.098 \cdot kip$

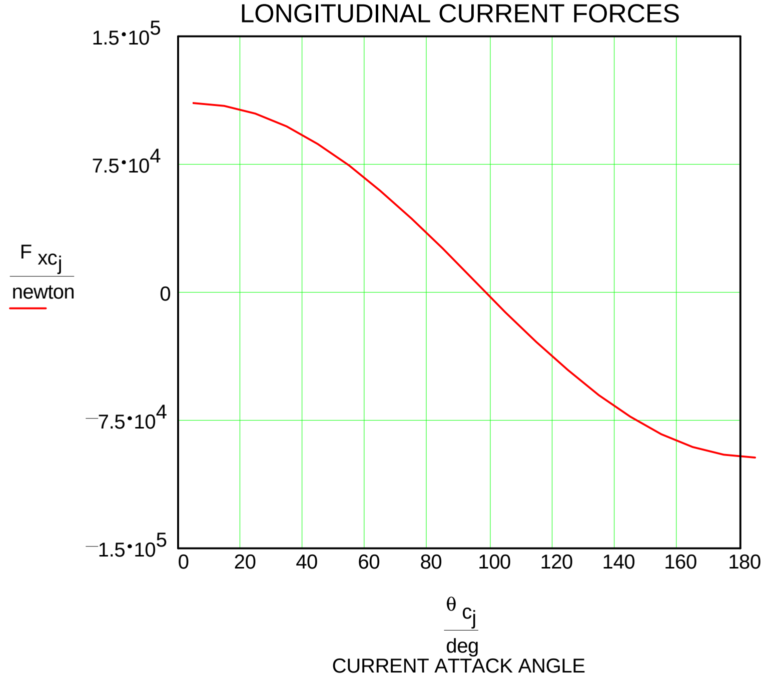
$$FORM := \frac{\left(100 \cdot Fxform_{18}\right) \cdot \left(V_c\right)^{-2}}{c_{long_{18}}}$$

$FORM = 21.844$

Calculate the longitudinal current forces

$F_{xc_j} := c_{long_j} \cdot V_c^2$ Total longitudinal current force

$\frac{\theta_{c_j}}{deg}$	$\frac{F_{xc_j}}{newton \cdot 10^2}$
0	1038.148
10	1022.639
20	976.562
30	901.26
40	798.914
50	672.476
60	525.548
70	362.21
80	186.664
90	$-3.736 \cdot 10^{-13}$
100	-186.664
110	-362.21
120	-525.548
130	-672.476
140	-798.914
150	-901.26
160	-976.562
170	-1022.639
180	-1038.148



$\max(F_{xc}) = 103814.803 \cdot newton$

CALCULATE THE YAW CURRENT MOMENTS

Develop the yaw current moment eccentricity ratio

The yaw current moment eccentricity ratio is developed from Figure xxx by selecting the appropriate value for "a" (y-intercept) and "b" (slope of curve) for the vessel analyzed. Table xxx lists various "a" and "b" values. This table is also provided below.

HULL	a y-intercept	b slope/deg	NOTES
Series 60	-0.291	0.00353	'boxy' hull like cargo ship or tanker
FFG	-0.201	0.00221	'rounded' fast warship hull
CVE-55	-0.168	0.00189	old fast attack carrier
SS-212	-0.244	0.00255	submarine

$a := -.168$ Y-intercept on Figure xxx for a series 60 vessel

$b := \frac{0.00189}{deg}$ Slope of curve on Figure xxx for a series 60 vessel

$e_{Lwl.} := a + b \cdot \theta_{c.}$ Ratio of eccentricity to waterline length j j

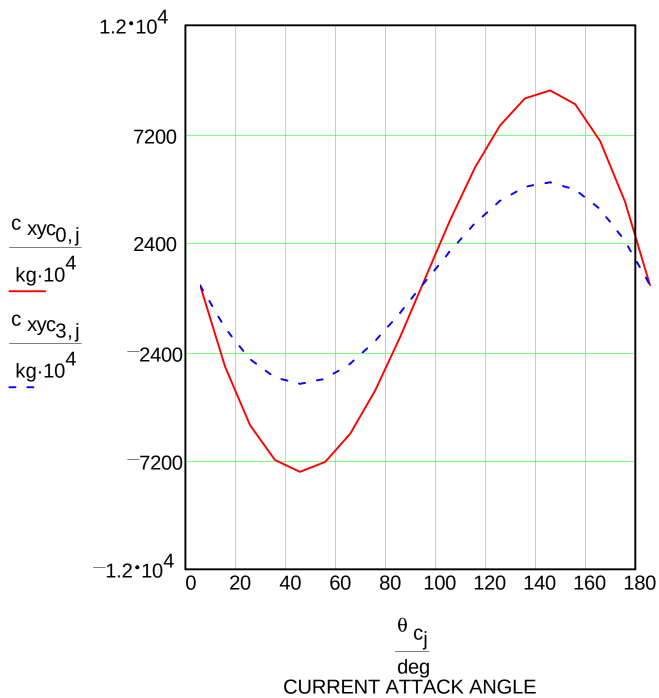
Develop the yaw current moment coefficients

$$c_{xyc_{i,j}} := \frac{F_{yc_{i,j}} \cdot e_{Lwl_j} \cdot Lwl}{V_c^{\,2}}$$

Equation to develop yaw current moment coefficients

$\frac{\theta_{c_j}}{deg}$	$\frac{c_{xyc_{0,j}}}{kg \cdot 10^4}$	$\frac{c_{xyc_{3,j}}}{kg \cdot 10^4}$
0	0	0
10	-3585.296	-1893.462
20	-6166.515	-3256.653
30	-7706.236	-4069.809
40	-8224.635	-4343.585
50	-7796.837	-4117.657
60	-6547.876	-3458.057
70	-4645.486	-2453.369
80	-2291.068	-1209.956
90	290.801	153.578
100	2863.834	1512.445
110	5192.014	2742.001
120	7051.558	3724.061
130	8242.371	4352.951
140	8598.482	4541.02
150	7997.038	4223.386
160	6365.435	3361.706
170	3686.29	1946.799
180	$-1.826 \cdot 10^{-11}$	$-9.643 \cdot 10^{-12}$

Graph of yaw current moment coefficients

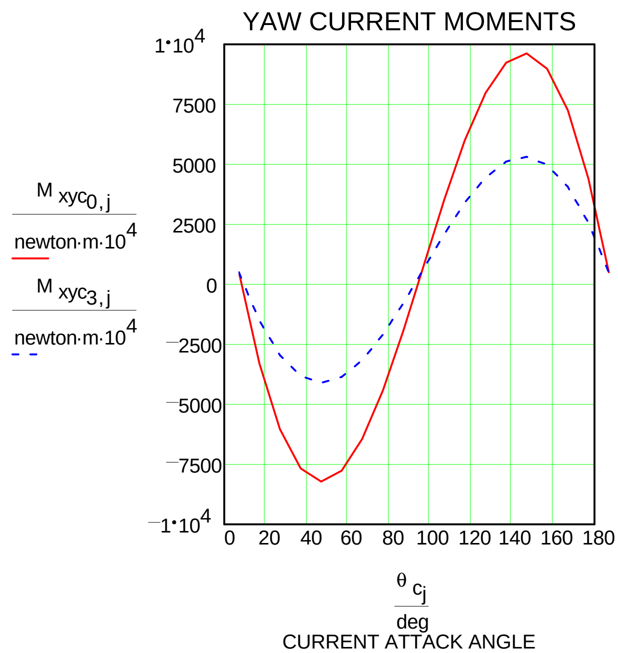


Calculate the yaw current moments

$$M_{xyc_{i,j}} := F_{yc_{i,j}} \cdot e_{Lwl_j} \cdot Lwl$$

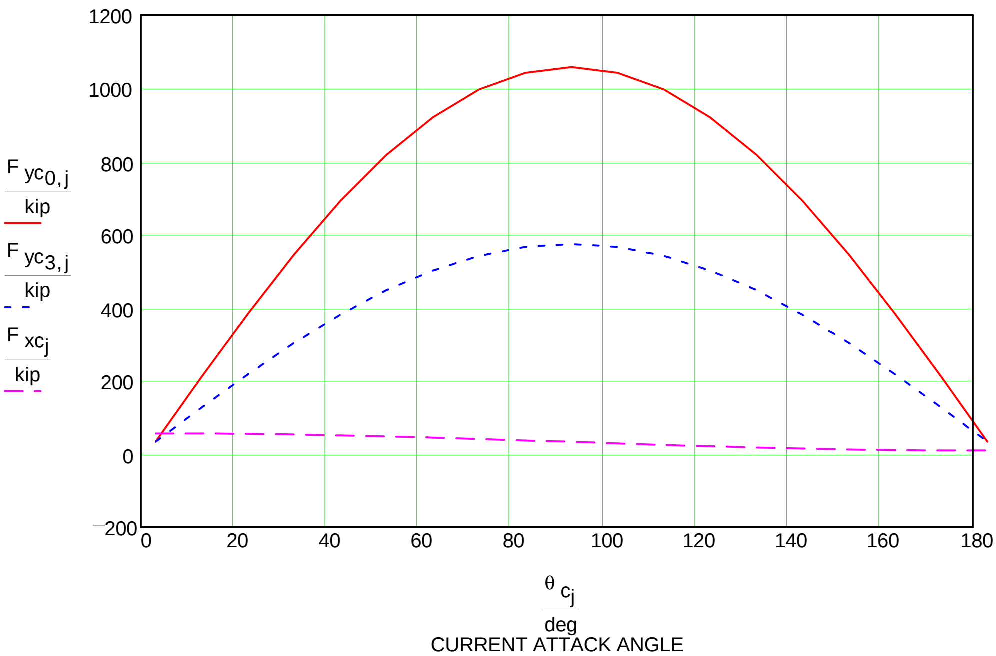
Equation xxx, section 4.4.3

$\frac{\theta_{c_j}}{deg}$	$\frac{M_{xyc_{0,j}}}{newton \cdot m \cdot 10^4}$	$\frac{M_{xyc_{3,j}}}{newton \cdot m \cdot 10^4}$
0	0	0
10	−3800.293	−2007.006
20	−6536.299	−3451.943
30	−8168.351	−4313.86
40	−8717.836	−4604.054
50	−8264.385	−4364.577
60	−6940.528	−3665.424
70	−4924.059	−2600.488
80	−2428.454	−1282.513
90	308.24	162.787
100	3035.568	1603.141
110	5503.36	2906.428
120	7474.415	3947.379
130	8736.635	4613.982
140	9114.101	4813.329
150	8476.591	4476.647
160	6747.147	3563.296
170	3907.344	2063.542
180	$-1.935 \cdot 10^{-11}$	$-1.022 \cdot 10^{-11}$



Plot current forces and moments in US units

PLOT TRANSVERSE AND LONGITUDINAL CURRENT FORCES



PLOT YAW CURRENT MOMENTS